N87-29877

SPACE STATION BASED OPTIONS FOR ORBITER DOCKING/BERTHING

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ABSTRACT

This paper describes conceptual efforts to develop a Space Station based system for docking and/or berthing the NSTS Orbiter. Past docking and berthing systems are reviewed, the general requirements and options for mating the Orbiter and Space Station are discussed, and the rationale for locating the system on the Station is established. One class of Station-based system is developed in several variations and evaluated with respect to weight distribution, loads, safety, reliability, viewing, and maintainability. An evolutionary presentation of the variations provides insight into the development process and the problems encountered. An overall evaluation of the Station-based variations compared to an optimized Orbiter-based system demonstrates the potential benefits of this approach as well as the issues that must be resolved to realize the benefits.

INTRODUCTION

Orbital activities have included the mating and demating of vehicles throughout the last twenty years, since the Apollo program used separate vehicles for translunar flight and lunar landing. Two basic approaches to vehicle mating have since emerged; docking and berthing. Docking refers to the connection made when the approach vehicle flies directly into the target vehicle, where the docking mechanism engages on impact and secures the vehicles together. Docking systems were developed for the Gemini, Apollo, and Apollo-Soyuz programs.

The Apollo system, shown in Figure (1), utilized a probe and drogue capture mechanism. The probe was mounted on the Command Module (CM) and the drogue on the Lunar Module (LM). With the probe extended, either vehicle could fly into the other, where the impact forced the probe into alignment and allowed capture latches to engage the drogue. The probe was then retracted and structural latches actuated around the interface perimeter to provide a pressurizable interface between the vehicles. The probe and drogue were removable from within the vehicles to permit crew transfer.

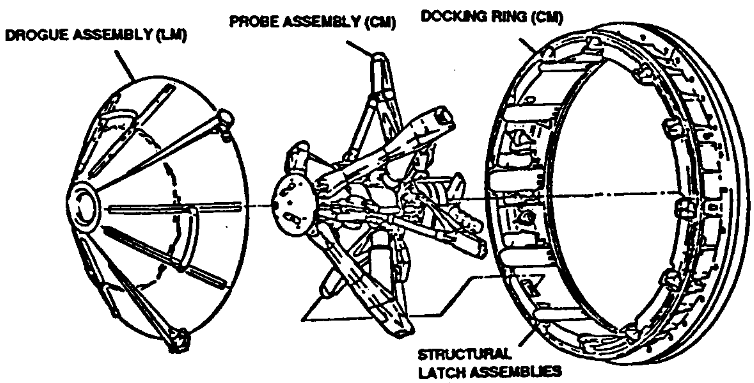

Figure 1. Probe-Drogue Capture Mechanism Provided Apollo Docking Capability

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The probe and drogue system was combined with a new one for the Apollo-Soyuz interface, shown in Figure (2). The active portion of the Soyuz interface consisted of a capture ring with alignment petals mounted on hydraulic struts. An identical interface without struts was provided on the Soyuz spacecraft. As the interfaces were driven together, the petals interlocked-and forced the interface rings into alignment, where capture latches around the perimeter secured the rings together. The hydraulic struts acted as shock absorbers and allowed the active ring to "float" during impact and alignment relative to the supporting structure. After damping, the active ring was retracted with a cable system and structural latches engaged to provide a pressurizable interface. Both Apollo and Soyuz interface systems depended on the closing velocity between vehicles to provide the force necessary to align the capture mechanisms.

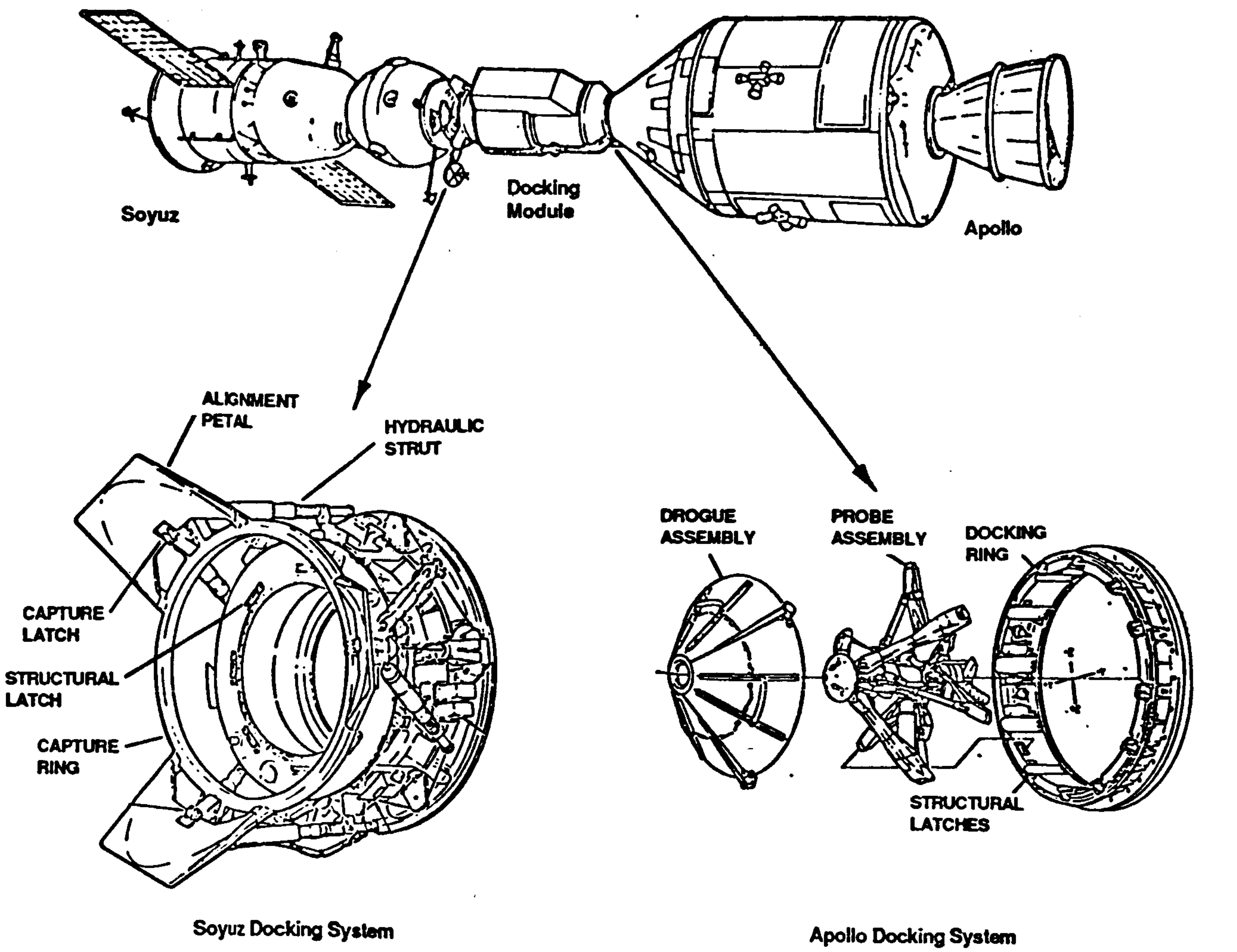

Figure 2. Ring/Petal Capture System Developed for Apollo-Soyuz Docking

With the advent of the Shuttle Orbiter and the Shuttle Remote Manipulator System (SRMS), berthing of space vehicles became possible. Berthing refers to the use of an intermediate mechanism, typically a manipulator, to capture the target vehicle and perform the maneuvers required to position the vehicles for the desired interface.

Berthing operations to date have included the capture and placement of satellites in the Orbiter payload bay, Figure (3), and the deberthing and deployment of satellite and other payloads, such as the 22,000 pound Long Duration Exposure Facility (LDEF). In a typical satellite berthing operation, the arm tracks and captures the satellite and stops any relative motion. The arm then performs the maneuvers necessary to place the satellite within the reach of the interface system in the payload bay. Capture latches engage the satellite, the arm is switched to a "limp" mode, the latches complete the interface, and the arm is disengaged.

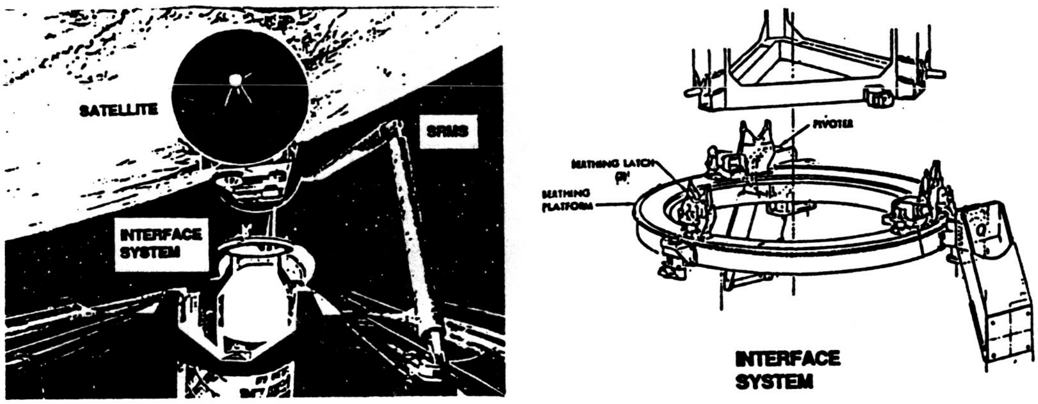

Figure 3. Manipulator Berthing Provides Controlled Mating Operations

The berthing approach is an attractive alternative to docking because no closing velocity is required for capture, reducing the risk of collision. In addition, manipulators are designed for accurate placement, and should be able to perform interface alignment more efficiently and without the contamination problems of jet thrusting. The disadvantage is that although the vehicle to vehicle interface may be simplified, the arm itself is an extremely complex element.

THE ORBITER-SPACE STATION INTERFACE

The interface between the Orbiter and the Space Station will be a critical one. The Station is planned to operate for 30 years or more and will depend on the Orbiter for consumables resupply and crew and payloads exchange. The type of interface selected will depend on a number of issues; the ability of the Canadian supplied Station manipulators to handle the mass of the Orbiter and to provide adequate reliability, and the tolerance of Station operations to docking related loads and contamination. Most importantly, the choice must resolve the risks associated with orbital operations and the mating of two vehicles each weighing in excess of 250,000 pounds. Berthing seems to represent the least risk approach, but Orbiter manipulator limitations make berthing totally reliant on the Station manipulators, which could make Station access impossible in the event of a catastrophic failure. Finally, the commercial nature of the Station will require an interface system with minimal overall cost, from development to operations and maintenance.

An example of a typical Orbiter-based interface system is shown in Figure (4). The mechanism is compatible with both docking and berthing approaches. The configuration is similar to the Soyuz interface system, although more sophisticated electromechanical struts are required to complete docking alignment and capture due to the offset of the Orbiter center of mass. The struts extend the capture ring and petals out of the payload bay, where interface contact and petal interlock force the interfaces into alignment. Interface contact may be initiated by direct fly-in or by manipulator placement. When the capture latches are engaged, the struts attenuate the relative motion, especially the induced rotation, and retract the capture ring onto the Orbiter transfer tunnel, where structural latches complete the interface.

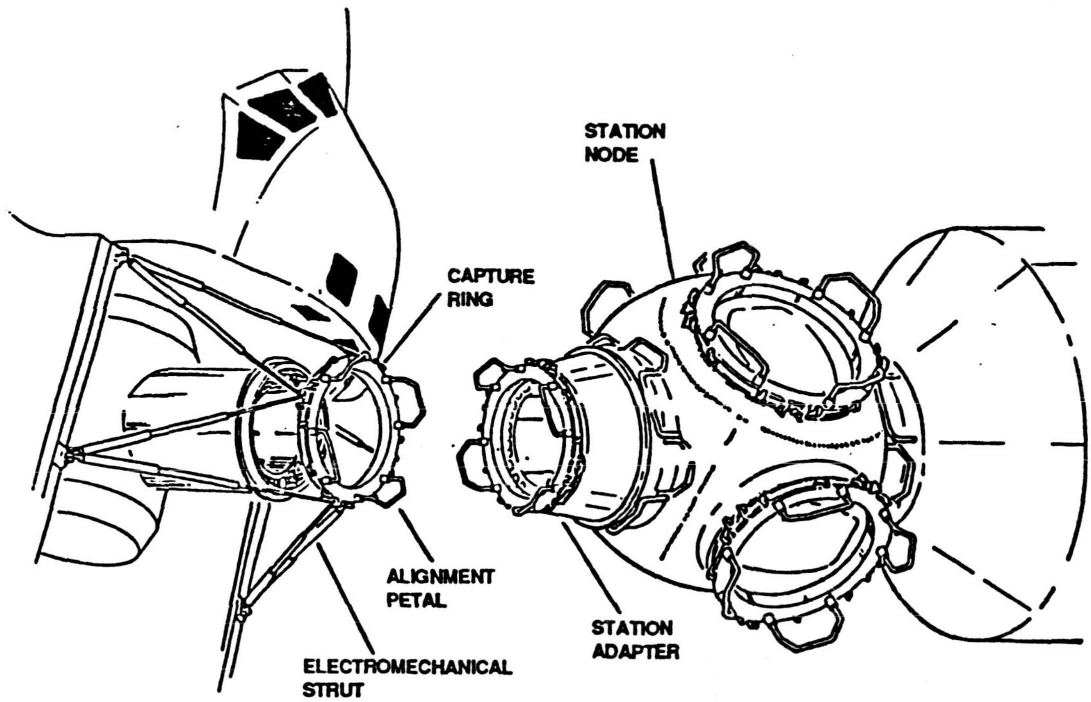

Figure 4. Typical Orbiter-Space Station Interface Concept Uses Modified Apollo-Soyuz Approach

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This type of system has a number of unique features: the long struts eliminate the need for a separate tunnel extension mechanism and provide a large capture envelope. The Station mounted adapter reduces the likelihood of collision damage to the pressurized portion of the Station and allows the Orbiter transfer tunnel to be smaller in diameter than the Station port. However, like most of the systems proposed over the last ten years, the bulk of the interface system is based in the Orbiter payload bay. Although this locates most of the control with the Orbiter, which reduces reliance on Station performance, it requires a substantial portion of the available payload bay volume and launch weight. The system shown will take up roughly one-tenth of the weight that is available for cargo. This penalty has prompted a reevaluation of interface concepts where the bulk of the system can remain on-orbit.

STATION-BASED INTERFACE SYSTEMS

A Station-based interface system requires one of two approaches. The interface system may be similar to the Orbiter-based system, but stored and installed on-orbit, or an entirely new configuration may be developed where the bulk of the system remains permanently with the Space Station. The first approach, shown in Figure (5), is operationally complex. System transfer and installation requires either dual manipulator operations, as shown, or some application of EVA or remote vehicle operations. Because the second approach is potentially less complex, it was selected for investigation in this study.

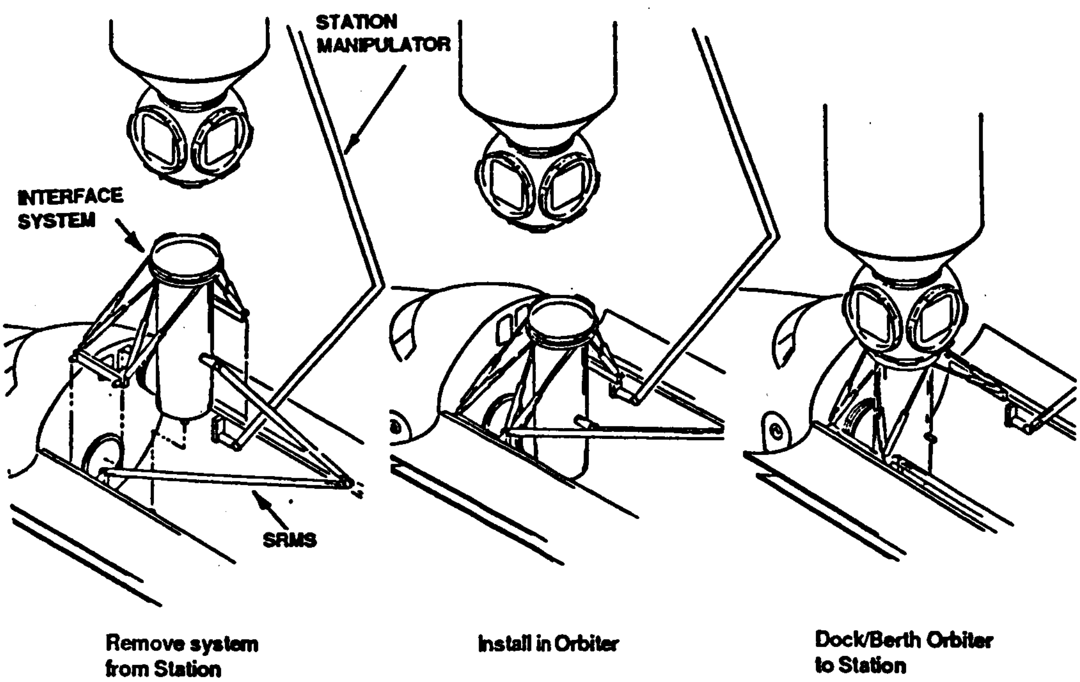

Figure 5. Orbital Transfer Requires Complex Installation Operations

The concept used as a starting point is shown in Figure (6). The basic system consists of a rigid transfer tunnel mounted on the target port and an alignment/capture/tunnel insertion assembly. The assembly consists of telescoping struts with alignment/capture mechanisms mounted on the ends. Ideally, the only hardware carried on the Orbiter is that required to attach to the capture mechanisms and to seal the transfer tunnel to the airlock hatch area. The telescoping struts have sufficient stroke to complete capture and attenuation before the bottom of the transfer tunnel approaches Orbiter structure. After attenuation, the telescoping retraction allows a controlled insertion of the tunnel into the payload bay. By using a primarily telescoping action and limiting the other degrees of freedom, the risk of joint runaway and collision, common to manipulator operations, is reduced.

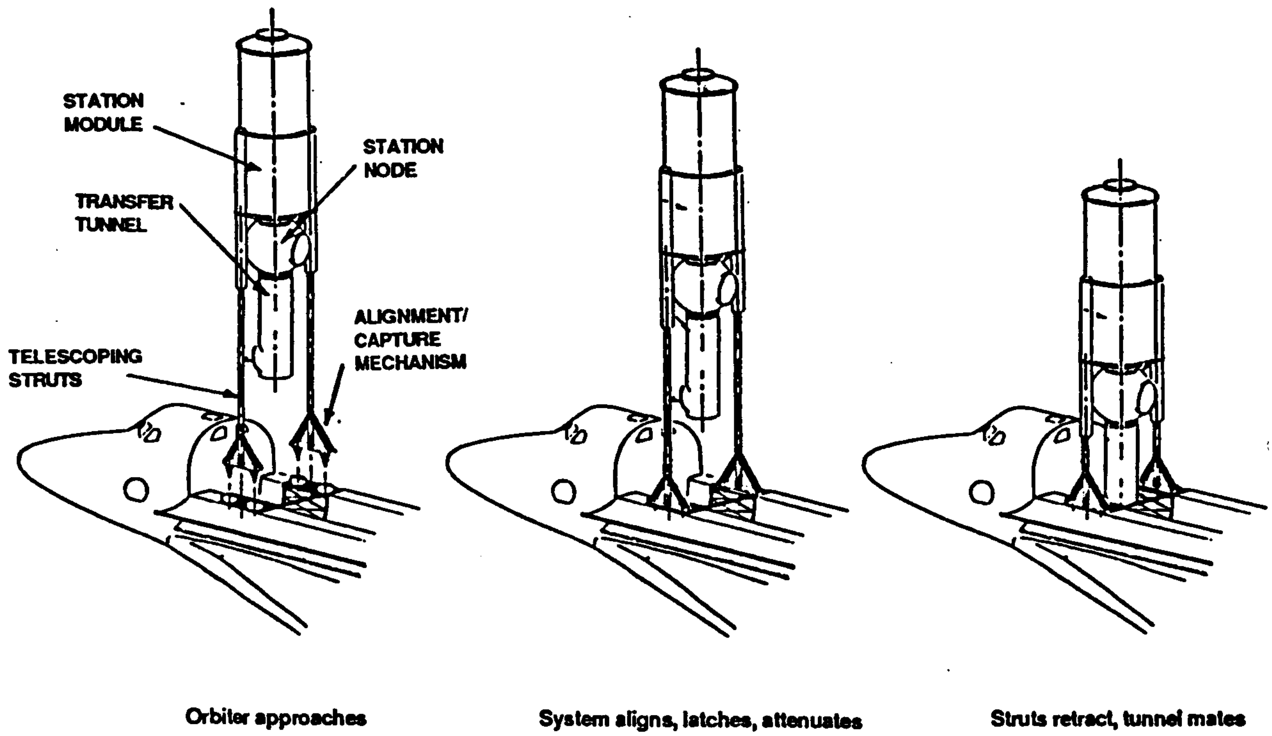

Figure 6. Telescoping Struts Provide Orbiter Capture and Station Tunnel Insertion

Concept 1. The first version of the Station-based system is shown in Figure (7). To minimize development costs, existing payload retention latches are used for the capture mechanism on the Orbiter, with two trunnion fittings on one strut and one on the other. The combination of two on one strut provides the ability to withstand pitching moments. The struts are mounted to the station through structure on existing ports. As the node is sized to fit in the payload bay, this configuration places the axes of the struts and the attached trunnions close to the Orbiter longerons and retention latches, minimizing the structure required to bring them into alignment. In addition, this configuration permits the entire strut assembly to be mounted to the node on the ground, avoiding on-orbit assembly.

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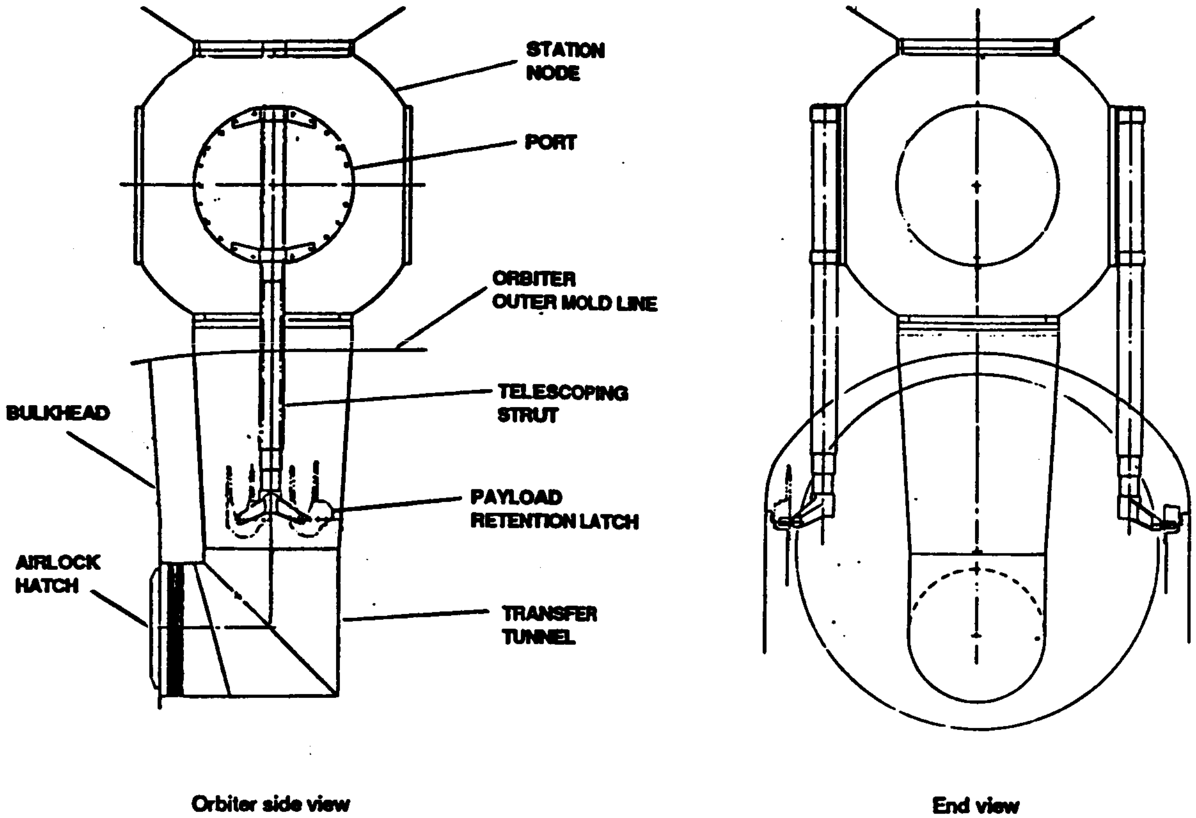

Figure 7. Existing Payload Retention Latches Provide Alignment and Capture Capability

The transfer tunnel assembly, Figure (8), is composed of two segments. The Orbiter portion incorporates a load isolating bellows element to prevent miscellaneous loads from being transferred into the Orbiter bulkhead. The bellows assembly also moves the interface away from the bulkhead, improving clearance between the Station tunnel and the bulkhead during insertion. The canted interface simplifies alignment and mating of the Orbiter and Station tunnel sections with the vertical insertion technique used.

Although the system is well packaged and uses proven hardware at the latching interface, the latches themselves limit system performance. Because latch actuation time is a minimum of 30 seconds, the system is suitable only for berthing operations, where the latch and trunnion can be held in proximity until the latches have engaged the trunnions sufficiently. To provide docking capability, latch actuation must be very rapid to insure capture before significant rebound occurs. For the Orbiter/Space Station interface this problem is especially acute because the contact point is roughly 40 feet from the Orbiter center of mass. Thus, although the large inertias of the Orbiter and the Station will tend to force the interface together, the resulting contact force will induce a substantial pitch moment and rotation on the Orbiter, complicating alignment and capture.

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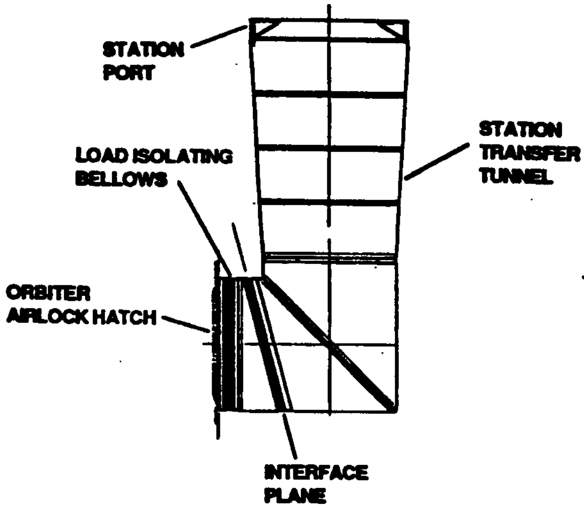


Figure 8. Tunnel Interface Simplifies Alignment, Isolates Loads

One way to insure capture is to replace the payload retention latch system with a probe and drogue interface like that used for Apollo, as shown in Figure (9). This modification provides rapid latch actuation, although the latch system will be somewhat complicated by the need to withstand the pitching moment while still providing misalignment tolerance. Some of the alignment may be accomplished by flexing of the telescoping struts themselves; sufficient attenuation stroke could soften the impact and reduce the induced pitching moment to make such a technique practical.

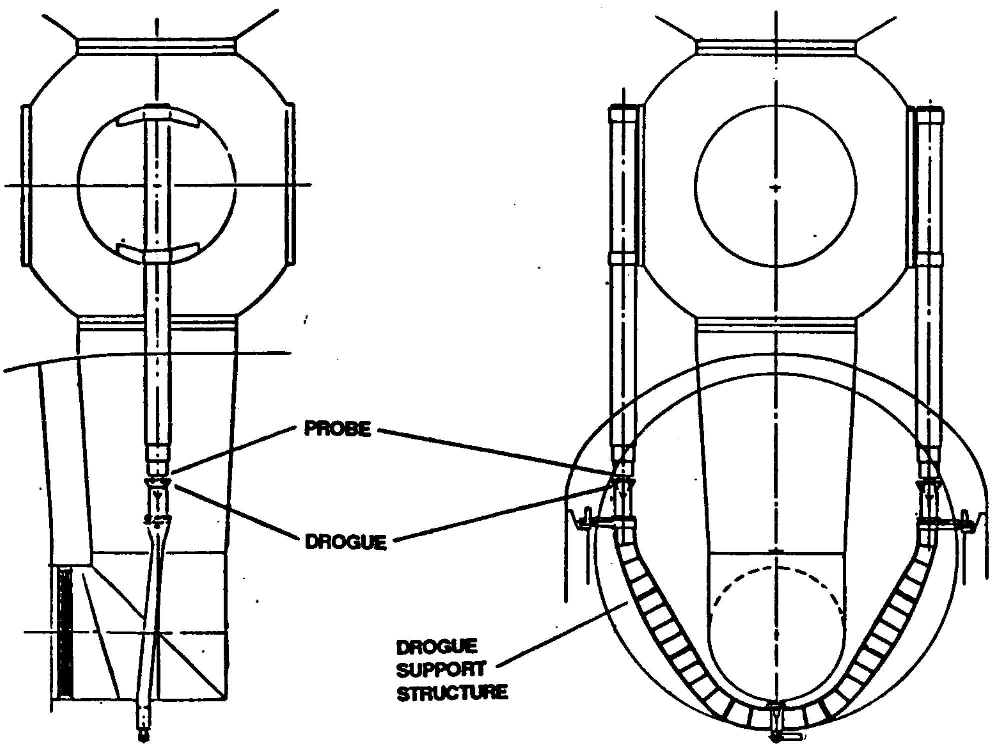


Figure 9. Probe-Drogue Capture Provides Docking Capability

The structural attachment between the latches and the Orbiter must also carry the induced pitch moment. This could be accomplished by mounting the support structure to two payload retention latches on one side, as in the first concept. However, because the two drogues must be fixed in all degrees of freedom to provide a stable target, a beam like the one shown can be incorporated to provide both latch support and moment transfer.

Replacing the payload retention latches with probe and drogue latches produces a configuration with both berthing and docking capability. Unfortunately, it does so at the expense of considerable additional hardware that must be carried in the Orbiter. Fortunately, further investigation of the Orbiter payload retention system revealed the possibility of bolting the latch support structure directly into the Orbiter longerons, as shown in Figure (10). This approach eliminates the retention latches, the supporting bridge and keel fittings, and the connecting beam. Additionally, it can be accomplished without Orbiter modifications as bolt locations are already available where the longeron bridges would otherwise be mounted.

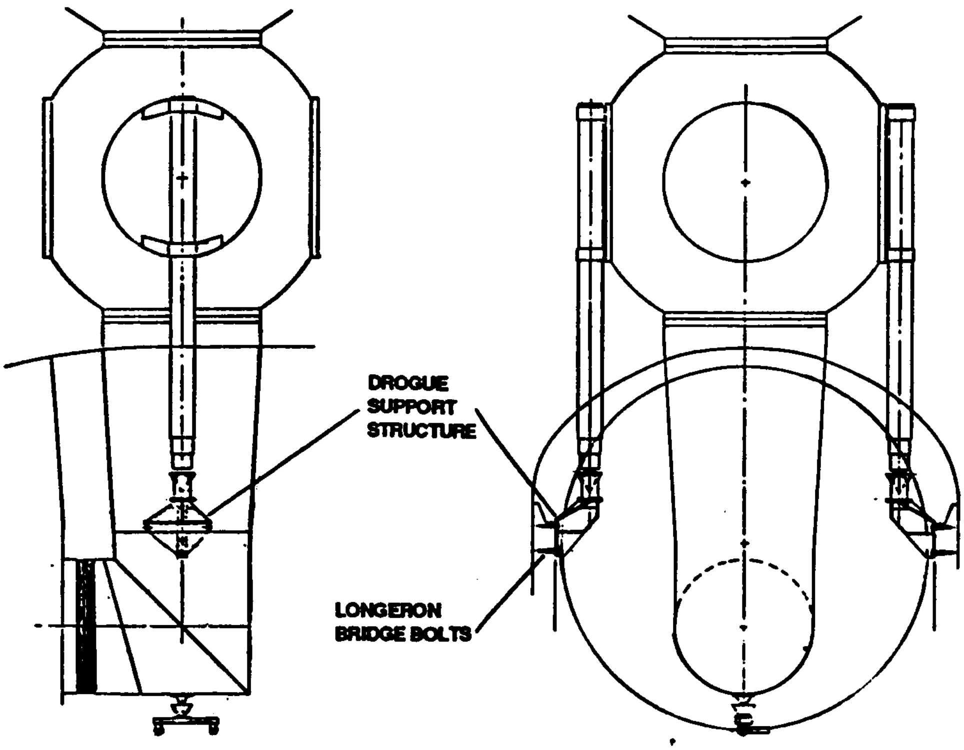


Figure 10. Direct Longeron Mounting Reduces Latch Support Requirements

Concept 2. The three versions of Concept 1 each represent a more or less viable means of attaching the Orbiter through struts that are symmetrical with respect to the target node and the Orbiter. Although the symmetry demonstrates certain advantages, it also has inherent drawbacks. The first is that mounting the struts on the node ports obstructs the ports themselves and prevents them from being attached to other pressurized elements. The second is that the basic strut configuration is not well suited to the expected load distribution, especially the pitch moment. For the symmetrical configuration, the entire moment must ultimately be taken out by strut bending.

An option that addresses these two concerns is shown in Figure (11). By locating the two struts fore and aft, the moment is taken out by strut tension and compression rather than bending. Also, moving the strut mounting from the port faces to the areas between the ports releases the port for attachment to other pressurized elements. With these improvements, however, come certain penalties. It is now impossible to preassemble the struts to the node because of packaging constraints, and the relocation of the struts moves them further from the Orbiter longerons so that additional structure is required to position the drogues. Finally, the superior pitch capability is traded for an induced roll, so that again some load will be taken in strut bending, and additional structure may be required to adequately transfer the roll moment from the latches to the Orbiter.

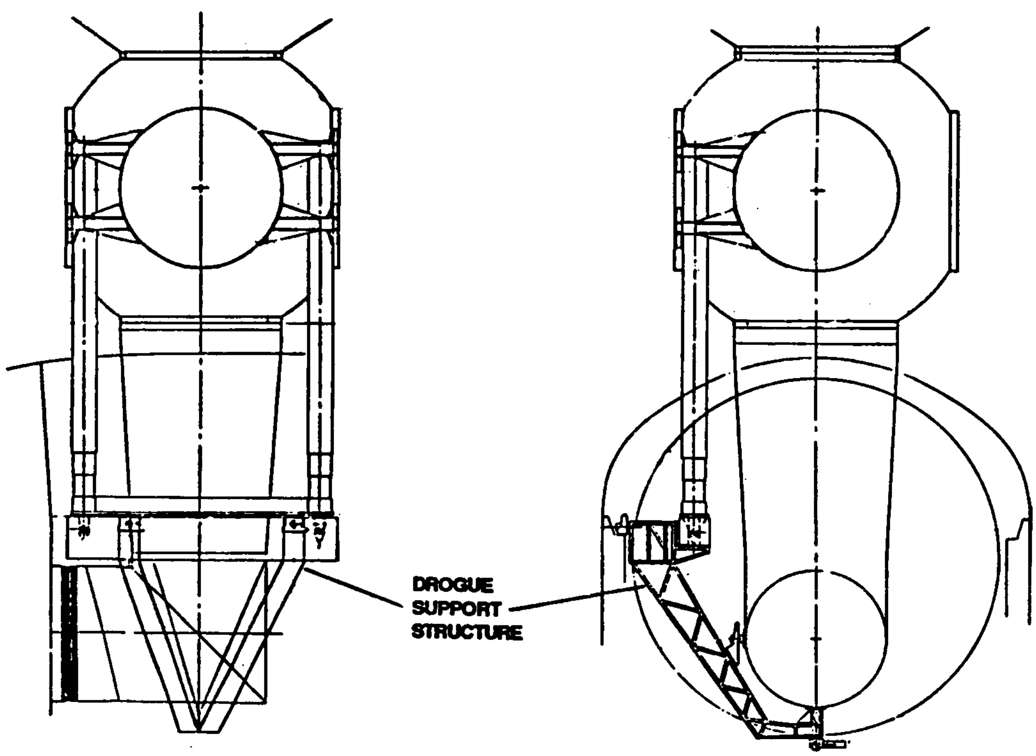


Figure 11. Fore/Aft Strut Placement Improves Pitch Load Capability

Concept 3. Both Concepts 1 and 2 suffer from some unsymmetrical loading which will require the telescoping mechanisms to resist the induced moment by bending. This limits their ability to utilize strut flex as an alignment technique and may drive the sizing of the struts. An alternative is shown in Figure (12). Four point contact provides symmetrical loading for both pitch and roll, and could allow alignment flex to drive strut sizing rather than moment capability. This configuration also differs from the previous two in that the drogues are now deployable. By raising them out of the payload bay the contact points are no longer close to Orbiter structure, where a missed capture could result in collision and damage. Although missed capture is a potential problem for the two strut configurations as well, the problem is more severe for the four strut approach because of the larger distance between probes and the increased difficulty of monitoring four points simultaneously.

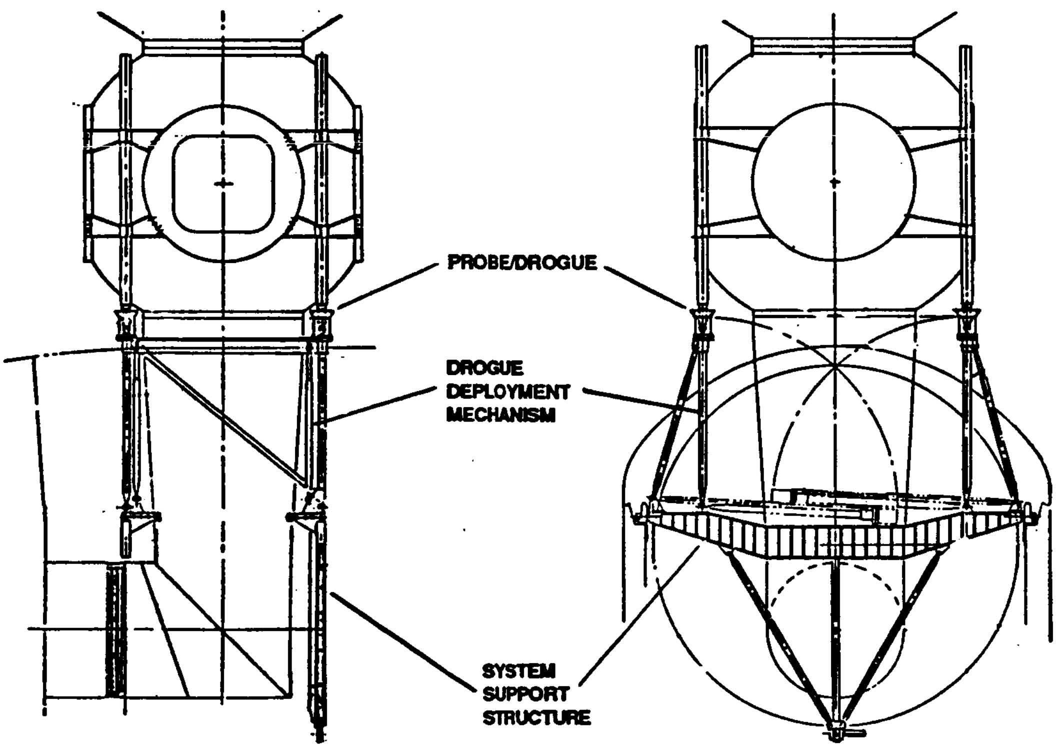


Figure 12. Raised Four-Point Contact Provides Symmetrical Loading, Reduced Collision Risk

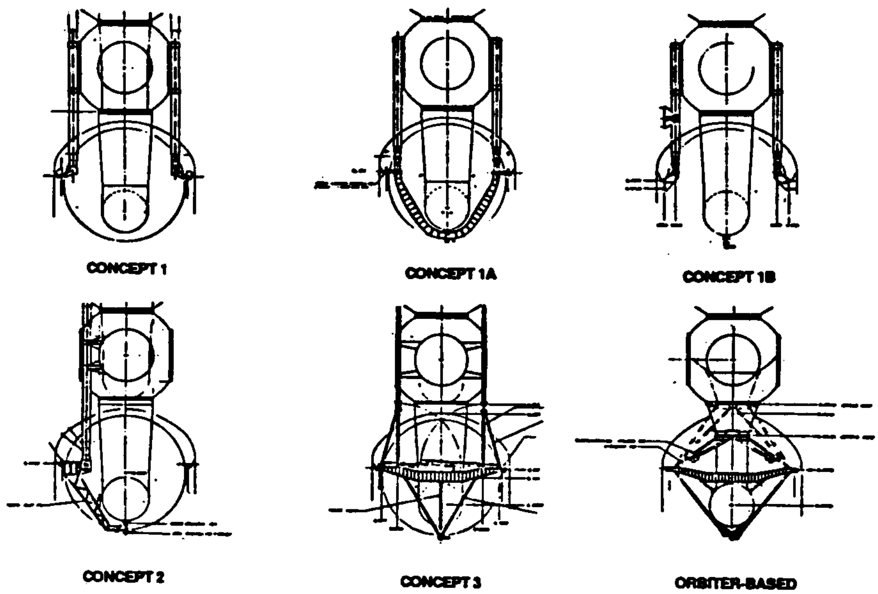
As with the other concepts, variations of this configuration may be possible which would reduce some of the structure required on the Orbiter, but the need for four, or at least three, contact points will require some additional hardware compared to a two strut approach. Another potential disadvantage with this particular configuration is that the support structure required occupies significantly more payload bay volume than the two strut options.

CONCEPT COMPARISON

The purpose of this study was to develop variations of the basic Station-based system, and to use the concepts developed to evaluate the potential of this type of system. To evaluate these concepts against the Orbiter-based system a number of discriminators were selected.

The key argument for a Station-based system is the weight distribution, so the most important factor is the amount of weight that must be carried by the Orbiter on each flight. In addition, the overall cost of the system depends on total weight, on system reliability, which defines maintenance requirements, and on maintainability, which affects the cost of the maintenance actions. The amount of risk inherent in the design is also crucial, as well as the efficiency with which the configuration handles mating loads. Finally, viewing was included as it affects the risk of collision and the ease with which the crew can monitor system operations. Although the list is by no means comprehensive, it represents a sampling of factors that can be used to perform a preliminary evaluation.

A summary of the approximate system weights and scorings for the other factors is shown in Figure (13). The scorings were on a subjective scale of 1 to 10 with 10 being the best. The top score in each category is boxed. Where the Orbiter-based system has the highest rating, both the Orbiter-based and highest Station-based score are boxed for comparison.



CONCEPT	TOTAL WEIGHT	STATION WEIGHT	ORBITER WEIGHT	LOADS	SAFETY	RELIAB.	VIEWING	MAINT.
1	3319	2275	1044	3	4	5	3	4
1A	3398	2277	1121	4	4	$\boxed{6}$	4	4
1B	$\boxed{2896}$	2277	$\boxed{619}$	4	4	$\boxed{6}$	4	$\boxed{5}$
2	3156	2293	863	5	4	$\boxed{6}$	$\boxed{5}$	4
3	3219	1348	1771	$\boxed{7}$	$\boxed{6}$	4	3	3
ORBITER-BASED	3430	667	2763	6	$\boxed{7}$	5	$\boxed{5}$	$\boxed{7}$

Figure 13. Station-Based Options Competitive with Orbiter-Based

In the area of Orbiter weight, Concept 1B is a dramatic improvement over the Orbiter-based system and most of the other Station-based concepts. Concept 3 offers the most efficient configuration for loads due to the large distance between latching points and the symmetry for both pitch and roll loads. Safety was evaluated based on the potential for collision after a missed capture; although the four point system provides capture at the same level above the Orbiter as the Orbiter-based system, the separate struts could allow capture of one or more points while missing with others, which makes the integral ring contact on the Orbiter-based system a slightly safer option. The reliability evaluation is based on the number and complexity of mechanisms required. Because Concepts 1A, 1B, and 2 all use two probe and drogue latches as opposed to four for Concept 3 and motor driven elements for Concept 1 and the Orbiter-based system, they should have somewhat better reliability. For viewing, Concept 2 is superior because both contact points are easily visible from the aft crew compartment windows within a small field of view. The other systems require scanning and, for Concept 3 and the Orbiter-based system, contact is made above the viewing plane. Finally, although the minimum amount of hardware required for Concept 1B makes it the most maintainable of the Station-based options, the ground maintainability of the Orbiter-based system is a clear advantage.

CONCLUSIONS

For the concepts identified and the discriminators selected, although no one concept is universally superior, the Station-based approach appears competitive with the Orbiter-based system. Although potentially substantial weight savings have been demonstrated, realization of this potential will depend on a number of issues. The real value of the recovered cargo capability is one: if the full capacity of the payload bay is not needed on every flight, then some of the potential savings are imaginary. A final assessment of the approach also will require an accurate evaluation of the increased costs of maintaining a Station-based system. Additional concerns are the significance of the loss of Orbiter operational autonomy and the need for detailed evaluation of the mechanisms required for alignment and capture. Nonetheless, in this preliminary evaluation, it appears that this type of Station-based system may provide a viable alternative to the more traditional Orbiter-based approach.

ACKNOWLEDGEMENTS

The author would like to acknowledge the contributions of those who participated in this project. Many helpful discussions and suggestions resulted in the development of the basic approach and options. In particular, the project could not have been completed without the assistance of Pete Buck, Bill Creasy, John Lewis, Gerry Malloy, and Warren Wooll.